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A slit phase contrast apparatus with modified phase plates for the examination of optical gratings and other objects with variations in one dimension

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With 5 figures in the text

Introduction and summary

In a lecture (Jan. 24, 1950) the writer analysed some new possibilities of utilizing the phase contrast method of Zernike for purely physical research, one of them being the study of periodic errors in optical gratings. This application originated from a discussion following a lecture by the author in the Optics Institute of Paris in the spring of 1949 and was there proposed by **Françon** and afterwards discussed between us. During the interval it was studied with apparatus both in Paris and in Stockholm and a common, final report of the work was edited in London, July 1950 (1, 2).

The apparatus described was constructed here to make such phase contrast studies sufficiently exact and convenient for a general application, primarily for the study of gratings. It is not necessary that the grating should already be mounted in a spectroscopic arrangement, though this is also possible in every case (2), as the apparatus also contains an entrance slit, and thus any concave or plane grating with an autocollimating lens could be put in front of it to be examined. For more general use and one particular application, phase contrast plates have been constructed to permit reduction of either the central fringe light or the diffracted light.

Main features of the apparatus

As seen in Fig. 1 and in the photograph Fig. 2, the simple apparatus consists of a single unit, supported either directly on the table by means of three foot screws, on optical benches with two rods, or on stands in an arbitrary position, horisontal or vertical, by intermediate columns passing through holes in the base.

After having been polarized in a separate polaroid A, the light enters through the entrance slit B, regulated by the micrometer C, and the beam is deflected by the totally reflecting prism D of stria-free quality situated immediately below the returning beam of light. To prevent any stray light from this part of the beam, a separate cover, not shown in the figures, isolates it backwards and sidewards. After having been diffracted in the grating E in either of the

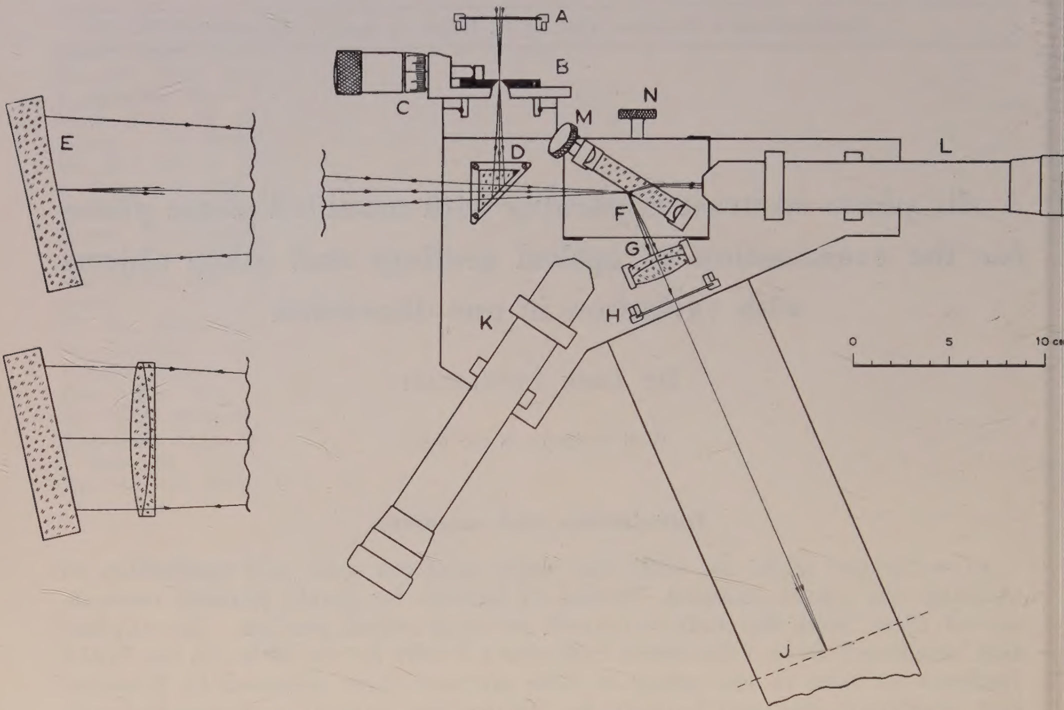

Fig. 1. Diagram of the apparatus. Only rays of the central fringe, not the side-diffracted rays, are shown.

mountings shown (Eagle or Littrow), the beam of monochromatic light for which the grating has been orientated, e. g. the green mercury line, enters the apparatus and should fall so that the sharp spectral line coincides with the slit in the phase plate F, which is constructed as described below. The light is reflected at the phase plate under the Brewsterian angle for the glass and is gathered by the achromatic lens G to give an image of the grating surface E in the plane J, after having passed a second polaroid H.

This image, which will appear in phase contrast, positive and negative in variable contrast, can be registered in different ways. After having observed it visually, through an eyepiece or a microscope, one could photograph it or register the intensity variation by means of a photo-multiplier tube with a recorder. For the first method, a movable plate-holder constructed here is of advantage, making it possible to make a series of photographs under various conditions on the same plate. In another device, the image field is traversed by a photo-multiplier tube behind a narrow slit and carried by a wagon, driven synchronously with the recorder.

The phase contrast slit is adjusted to coincide with the spectral line by means of two microscopes K and L with low magnification (40 times) and long working distance. Their axes can be tilted to follow the line throughout its whole extension. According to Fig. 2, the same microscope can be used and moved from K to L. At K, the ends of the line, which fall on two strips, are

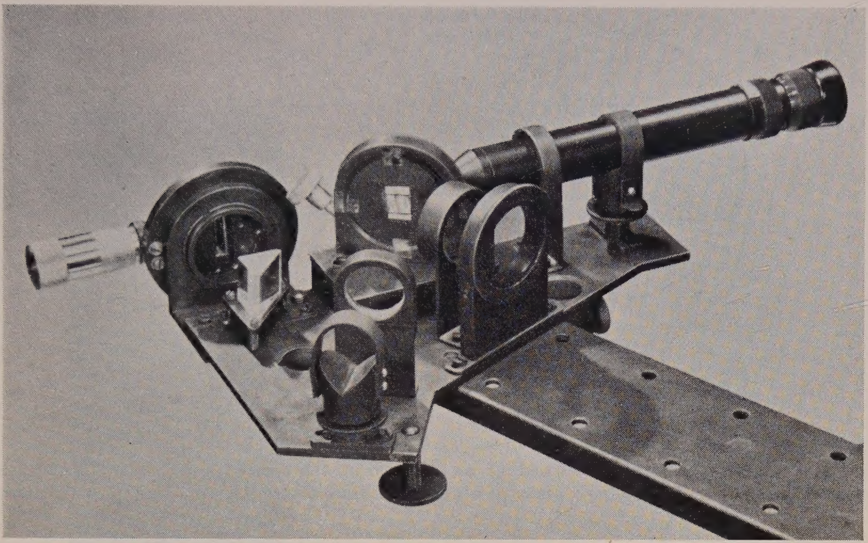

Fig. 2. Side view of the apparatus.

viewed, and by the screws M and N the phase plate can be rotated and displaced sidewards. The latter adjustment is performed with the microscope L. As the phase contrast plate is in one case transparent and in the other opaque but surrounded by transparent areas, one can bring the slit and the line to cover each other fully by means of the screw N, and, at the same time, regulate the slit width by the micrometer C. It has, in actual use, proved better to place the microscope K in the exit beam direction when adjusting with it.

When a special entrance slit is used, as in a complete spectrograph, the parts B, C, and D, mounted on separate shelves, are not used and can be excluded.

The phase contrast plates

On account of its wide possibilities, the type of phase contrast plate invented by Françon and Nomarski (3) earlier this year has been chosen and further developed. Its characteristics can only be shortly described in the shape it has received here, and the theory of its various applications will follow later.

The shift in phase between the central fringe light and the diffracted light is caused by their different paths when reflected at two parallell surfaces one, of them being glass. The Brewsterian angel i_B is a suitable angle of reflection as evidently the reflected intensity can be reduced nearly to zero by polaroids.

On a well-polished optical flat a metallic layer, of aluminium or other metal, is evaporated in vacuo. Its increasing thickness is controlled by a barrier-layer cell incorporated in the bell, directly if the metallic layer is still somewhat transparent even at the end of the procedure, otherwise with a special light beam traversing a layer with a proportionally smaller deposit. Soon after breaking the vacuum, a slit is formed with a special cut to regenerate the glass surface.

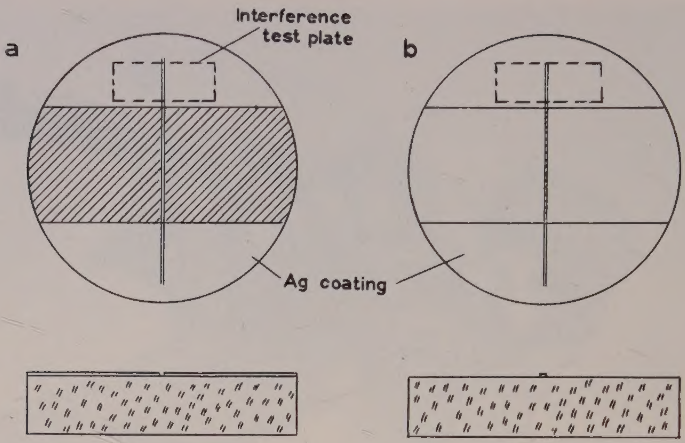

Fig. 3. a) Phase contrast plate according to Françon and Nomarski with device for measuring the step depth, b) Modified phase plate to obtain the light attenuation in the opposite direction.

This slit, with a width proper to the application, is located at about the centre of the round glass, Fig. 3 a. It is also possible to cover the slit area during evaporation with a tungsten wire or metal band, though the edges are in this case somewhat less steep.

As against most of the phase contrast applications in microscopy, we must here make the phase plate so exact as to correspond to measurement accuracy. Moreover in microscopy, one is rather far from the theoretical physical demands for optimal and quantitative physical phase contrast. Therefore, amongst other things the phase must be near $\lambda/4$, $3\,\lambda/4$, $5\,\lambda/4$, or a higher odd multiple.

The thickness of the layer should, for the first of these cases, be $e = \lambda/8 \cos i_B$, slightly corrected for phase shift differences on reflexion, and proportionately more for the larger steps, which may have some advantage. Although for known reasons e is not critical, it is not sufficient to measure it with ordinary Fizeau interferences, as they are too broad. We use here the multiple interferences described by Tolansky (4) by evaporating silver at both ends of the slit to full opacity, putting a small test plate on the plate as shown in Fig. 3, its base silvered to 80—90 per cent reflexion, and regarding and photographing it under the microscope in reflected light. The dark fringes are very sharp, as shown in the microphotograph Fig. 4, and allow a measurement to about $\pm$ 1/200 of a fringe distance, i. e. an error in e of $\pm$ 15 A, which is quite sufficient for our purpose.

Often in phase contrast technique, it is necessary to absorb or diminish the intensity of the central spot in order to increase the contrast and allow the detection of very small phase differences (5), such as are common in most spectroscopic gratings. But the opposite may also be desirable, namely to increase the central spot intensity in respect to the light diffracted on account of local phase anomalies, or, which gives the same result, to decrease the diffracted light. As shown by Erdmann (6), this technique is of advantage in the application of the phase contrast method to schlieren recording. The comparison of the two cases is given in Fig. 5 a and b, where the same scale was used for the

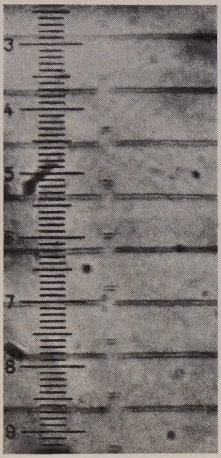

Fig. 4. Multiple interference fringes in reflected sodium D_1D_2 light, about the 70th order. The step corresponds to 0.266 of the fringe distance.

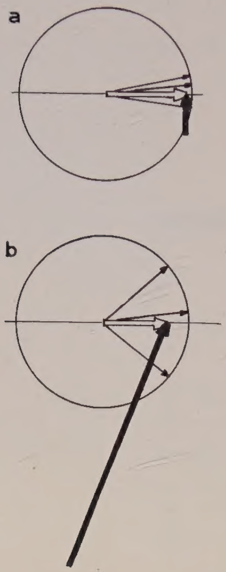

Fig. 5. Vector representation of the behavior of the two types of phase plates. The empty broad vector is the resulting light without phase change, the full broad one after having passed the phase plates.

diffracted light vectors. In case b, the angle between the central spot vector and the unchanged resulting vector is generally not so critical, as the individual light vectors are distributed over a larger part of the circle and often include several turns. For this purpose the writer has designed a phase plate, Fig. 3 b, where the surrounding light can be decreased continuously in the larger area, while the light of the central fringe remains approximately constant. Mr. ERDMANN, during a short stay in Stockholm, and the writer have made schlieren photographs with the phase contrast method in order to settle the proper sensitivity range. The central metallic strip ought to be opaque. The manufacture of this type of plate is only slightly more laborious than of those according to Fig. 3 a.

Analyses of results obtained with this apparatus will appear in later publications.

Optics Laboratory, Royal Institute of Technology, Stockholm 26, November 1950.

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